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Dynamic BIM component recommendation method based on probabilistic matrix factorization and grey model

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ABSTRACT

With rapid advances in building information modeling (BIM), a huge amount of BIM components has been built to increase design efficiency. Meanwhile, finding the appropriate BIM component in the huge library has become a challenge. Besides the methods of case-based reasoning (CBR) or multi-attribute decision model (MADM), the probabilistic matrix factorization (PMF) method of a recommendation system can be an efficient alternative. However, the user behavior patterns (i.e., the rating matrices) are changing with time to influence the recommendation precision. Therefore, this study aims to enhance the dynamic recommendation ability for BIM components by proposing a hybrid probabilistic matrix factorization method (PMF-GMn). The latent user preference matrix and the latent BIM component feature matrix can be generated by the PMF method from the rating matrix. Then, the predicted latent matrices can be obtained by the optimized grey model. Finally, the predicted latent matrices are further combined into the predicted rating matrix to recommend the appropriate BIM components. An illustrative example of the prefabricated building design is used to demonstrate the feasibility. This experiment is implemented by inviting twenty users to use the proposed SharePBIM platform for five months. The statistical results indicated that PMF-GMn can provide better performance than PMF in both two criteria of RMSE and Recall@k.

1. Introduction

The prefabricated building, owing to its advantages of less construction waste, financial savings, standard quality, shorter construction period, and safety, has become an important issue of construction industrialization and city sustainability. The integration with building information modeling (BIM) can promote the development of prefabricated building. One of the major applications is to build and use the BIM components of prefabricated buildings. BIM components are not only the 3D models of real-world objects but also the carriers of information and knowledge. BIM components are conductive to deliver and share building knowledge.

The amount of BIM component has increased with wide applications of BIM. A large number of public or private BIM libraries have been built to help the knowledge sharing and the design efficiency, such as ancient architecture, rail transport, mechanical electrical and plumbing (MEP) and prefabricated building [1–4]. The integrations of BIM components and prefabricated buildings also demonstrated satisfying performance in the processes of design [4,5], construction [6,7], and operation [8,9]. Besides, many studies built up platforms (or frameworks) of the prefabricated building with BIM component libraries [3,4]. They also formalized the knowledge management of BIM components, including production, uploading, searching and reusing.

However, as the number of BIM components increases significantly, locating the appropriate BIM component has become a challenge. Furthermore, designers also expect that the appropriate BIM components can be recommended in the design process. In the recommendation of BIM components, Case-Based Reasoning (CBR) and multi-attribute decision making model (MADM) are common methods to rank components by rating. In practice, it's hard for users to rate lots of components and the user preference may involve bias in the evaluation process. Therefore, a recommendation system based on user behavior patterns is more convenient and objective than CBR or MADM.

In the recommendation system, probabilistic matrix factorization (PMF) is a common method that recommends suitable components by generating user behavior patterns. PMF has been widely used in the recommendation of book, movie, music, online shopping and so on, but

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is less commonly used in the recommendation of BIM components. Besides, with the rapid development of building information modeling, the amount of BIM components increases significantly. User behavior patterns are also changing with time, affecting the precision of the recommendation. Therefore, the integration with prediction methods can enhance the quality of recommendation.

Hence, this paper aims to propose a BIM component recommendation method based on the dynamic probabilistic matrix factorization method. First, PMF is used to generate the latent vectors of user behavior patterns in different periods, in which the user behavior pattern can be represented as the rating matrix and constructed by user preferences and BIM components. Then, the optimized grey model is adopted to predict the tendency of latent vectors. Finally, the predicted latent vectors are combined to obtain a predicted rating matrix to recommend BIM components.

To demonstrate the effectiveness of the proposed recommendation method, this paper also develops a knowledge sharing platform, including more than 400 BIM components of prefabricated building, named SharePBIM (sharing platform for prefabricated building BIM components). Twenty users are invited to use SharePBIM for five months to validate the proposed method. Results show that the proposed method is able to accurately predict the latent vectors and effectively recommend appropriate BIM components for users.

2. Literature review

2.1. BIM component library and applications

The establishment, storage, retrieval, and utilization of BIM components are effective approaches to promote design efficiency. Therefore, many studies devoted to the applications of BIM component libraries and the integration with knowledge management. Wang et al. [1] developed BIM components of ancient architecture by connecting the maintenance information in BIM components with the extended database. Jia et al. [2] introduced a construction process based on BIM component library for ancient buildings and also apply GIS (Geographic Information System) to integrate the surrounding information. Park et al. [3] presented a system that incorporated BIM and GIS to evaluate the cost of the national road with standard BIM components. The system was able to analyze the cross section and provide reasonable decision making for the best of route selection. Yuan et al. [4] proposed the Design for Manufacture and Assembly (DFMA) for prefabricated building design and created lots of BIM components. They combined the DFMA into the BIM parametric design to develop an efficient concept and design process.

Not only BIM components, many studies also devoted to knowledge query related BIM components. Lee et al. [10] developed a design support system based on automatic rule checking and CBR to recommend BIM components according to regulations in the design phase. Maintenance teams can easily receive information and knowledge from previous experience and trace maintenance operation history of building elements. Kim et al. [11] presented the Modelica library for BIM-based building energy simulation (Modelica BIM library) using an Object-Oriented Physical Modeling (OOPM) approach and Modelica. Pavan et al. [12] introduced the INNOVance research project to promote a radical innovation into the Italian construction sector by creating a rich database.

Many researchers further studied knowledge acquisition and reuse of BIM components in the building lifecycle. Deshpande et al. [13] discussed knowledge acquired during the design and construction processes and presented a framework to enable the application of BIM components to support the organization process. Ding et al. [14] established an ontology-based framework for the knowledge of construction risk management in the BIM environment. The research proposed a method to connect BIM components and the risk management knowledge from ontology. Karan and Irizarry [15] translated building elements and GIS data into a semantic web and a set of standardized ontology; This process integrates and queries the heterogeneous spatial and temporal data with BIM components.

The above literature indicated that BIM components can carry rich information and knowledge and make better decisions. Most of BIM query adopted CBR or MADM. However, when the amount of BIM components is large, it's difficult for users to evaluate all indicators of components in practice and also users may have the different judgement in different time period. Therefore, a recommendation system based on user behavior patterns becomes an option to solve the problem.

2.2. Recommendation systems

Recommendation systems are often used to suggest the most appropriate components based on user preferences. Recommendation systems have been widely used in the field of e-commerce, entertainment, engineering, manufacturing, and knowledge management. There are three main recommendation filtering techniques:

(1) Content-based filtering. This filtering is based on the similarity with what the user used to like, and it focuses on analyzing the different component attributes. Various profiles of user interests are used to build the relationship between different documents within a corpus. Vector space model (e.g., Term Frequency Inverse Document Frequency) or probabilistic model (e.g., naïve Bayes classifier, decision trees, or neural networks) is widely used for content-based filtering.
(2) Collaborative filtering. This filtering provides recommendations based on the patterns of ratings or the usage records without exogenous information about either components or users. Collaborative filtering technique works by building a database (user-component matrix) of preference for components by users. Then, it can match users with relevant interest and preference by calculating similarities between their profiles to make recommendations.
(3) Hybrid filtering. To avoid the limitations of single recommendation mentioned above, sometimes the hybrid filtering is used to provide a flexible recommendation based on the combination with different filtering techniques. The hybrid filtering can be conducted in many ways, e.g., implementing a separate algorithm and combining the results.

Recommendation system has demonstrated well applications in many areas. Recently, the recommendation system has been also used in the AEC industry [16–18]. Besides, many studies try to integrate prediction models, such as neural network or grey model, into the recommendation system to better reflect user preferences.

As one of the collaborative filtering method, PMF has many successful applications in recommendation, including the Netflix prize problem, television shows, or songs. In general, PMF obtains the latent features of both users and items from the rating matrix by mapping both users and items to a joint low dimensional latent feature space, and then make prediction. PMF improves the performance of recommendation system. However, user preferences and item features would change over time that has great effect on the recommendation system. There is still a lack of methods for modeling the evolution of user preferences and item features.

2.3. Grey model

Grey model has been successfully adopted in many fields. The most commonly used grey model is GM (1,1). GM (1,1) indicates the first-order model and only contains one variable. The essence of the grey